PREPARATION AND EXECUTION OF THE FIRST FLIGHT OF A SMALL FIXED WING UAV, FROM THE (TEST) PILOT POINT OF VIEW.

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Abstract:

The first flight or a maiden flight of a new aircraft is always a special event. This applies to all aircrafts, regardless of their size and weight. In the case of non-autonomous unmanned aircraft systems (UAS) as well as manned aircrafts, the test pilot must prepare himself and the aircraft particularly for this event. This preparation is particularly more important if there is no possibility to test and fly the aircraft under test before the first flight, in a simulator or other ground-based facilities. And furthermore, no aerodynamic data set of the new aircraft from computer simulations or wind tunnel tests are available. The UAS pilot must therefore look for ways to optimally prepare the first flight of the aircraft under test to carry out this flight safely and successfully. The only remaining way to prepare the first flight in this Example were a lot of ground tests, low speed, and in particular high-speed taxi tests. To test the systems of the aircraft on ground and to familiarize the pilot with the aircraft. With this report I would like to describe the essential points that have enabled me to successfully carry out the first flight of the TORNADO II demonstrator UAS.

1. Introduction

In this case, the unmanned aircraft system under test is a demonstrator for a generic next generation multi role combat aircraft.

The UAS was developed and built as part of a privately funded study to investigate a 5th generation airframe design. The airframe of the aircraft was made of the oldest natural composite material on earth, from various types of wood and was completely developed and built by the author. The Tornado II is a 10,8% scale remotely piloted research fixed wing aircraft, designed to demonstrate first of all the aerodynamic concept of the aircraft design in real flight.

The wingspan of the aircraft is 1.03 meter (m), and it has a length of 1.48 m. According to [1] this UAS could assigned to Group 1, 0-20 lbs, with a take- off weight of 3572 grams (7,87 lbs). Please see figure 1.

Fig. 1 The Demonstrator UAS, Photograph G. Leonhardt

The systems necessary to operate the aircraft are formed from available commercial-of-the-shelf products and the number of aircraft systems are reduced to the minimum. The demonstrator is powered by two electrically driven impellers, so-called electric ducted fans, and lithium polymer batteries. A commercial off-the-shelf available computer radio control system (CRCS) JETI DC-14 [2] is used for control, navigation and telemetry. This system is almost a real experimental digital flight control system. With the restriction that it is operated in the so-called rate control mode and later in SAS Mode too, including a voice information and warning system. Or in other words, as a complete external cockpit for an external pilot of small UAVs. Please see figure 2.

Fig. 2 CRCS DC- 14, Photograph G. Leonhardt

2. Risk assessment

In addition to the technical preparations and inspections of the aircraft systems and the conditions and contents defined in the test program a risk assessment was carried out. The content of this evaluation was to determine which risk factors are to be classified in the category catastrophic and which possibilities of risk minimization are available for the preparation of the first flight. The results of this evaluation were identified by eight main factors. Initially, the sequence of the factors mentioned does not play a significant role. To be able to make a safe maiden flight:

1. The necessary user software for the aircraft is installed in the CRCS and all functions are tested.
2. The data- link connection between the ground station (CRCS) and the aircraft receiver must be safe and reliable.
3. The center of gravity of the aircraft must be precisely determined and adjusted.
4. The propulsion system of the aircraft must have sufficient Thrust/ power to drive the aircraft safely.
5. The control surfaces of the aircraft must be designed and adjusted accordingly. To generate enough control power, but also not too much to avoid the risk of pilots induced oscillations.
6. During the low speed and high-speed taxi tests, the pilot must familiarize himself with the operation and characteristics of the aircraft so that he can agree to the execution of the first flight.
7. The calculated speeds must be observed and adhered to.
8. The weather conditions defined in the test program for the taxi tests and the first flight must be given.

3. Preparation for the first flight

For the final preparation of the aircraft (PT2) for the first flight, the taxi test should provide the necessary technical data, show the reliability of the aircraft and create confidence in the aircraft and its systems and system components. Familiarizing the test pilot with the characteristics and operation of the new aircraft via the remote control system was also an important objectiv of this taxi testing, as other options were not available. The taxi testing began on September 8th, 2021 and was initially carried out with the aim of mechanically and software-technically setting the center position and the maximum steering deflections of the nose landing gear and optimizing them through corresponding taxi tests (low speed taxi tests) in such a way that the greatest possible steering deflections are given at low taxi speeds. In contrast, the aircraft should not tend to oscillations (PIO) around the yaw axis at maximum taxi speed (high speed taxi tests). Likewise, the aircraft should taxi straight ahead without corrections for as long as possible. A good compromise could be achieved for all three requirements through the mechanical settings and software adjustments. However, minor corrections when taxiing straight remain unavoidable and are depend on the ground conditions, weather conditions and mechanical tolerances in the landing gear and control system. The landing gear withstood the forces and moments occurring during the taxi tests without damage. The aircraft also survived an unintentionally initiated asymmetric landing from a low altitude during the second hop without any visible damage to the airframe and the landing gear. In this case, all taxi tests were carried out with no wind.

The next step was to check the control surfaces effectiveness for elevator, rudder and aileron and to check the effective direction of these control surfaces in relation to the control inputs on the respective control stick during high speed taxi tests and first hops. Very important here was the definition and verification of the parameters for the software defined control surface deflection movement. Behind this is the possibility of the FCS (CRCS) to generate an exponential movement of the control surfaces from a linear movement of the control stick via software. This can help minimize the likelihood of PIO during first flight.

This was followed by tests to check the rotation ability around the pitch axis (nose rotation capability). The control technique for these experiments is relatively simple, the aircraft is centered on the beginning of the runway, and the elevator stick is pulled fully aft and held in that position. Now the power of the engines is increased and the aircraft accelerates until the rotation around the pitch axis begins. At about 8° pitch angle, the stick is brought back to neutral position and the thrust is quickly reduced again to prevent takeoff of the aircraft and to stay well below lift-off velocity (V_{LOF}). [3]

The results of these tests showed that the set center of gravity (CG) matched the constructively selected and fixed trim position of the horizontal stabilizers, the aircraft did not rotate independently until it reached the velocity for rotation (V_R) without control inputs and the behavior of the aircraft around the pitch axis was stable up to neutral, the position of the main landing gear in relation to the center of gravity and the sizes of the horizontal stabilizers, the elevators and the elevators deflection angles have apparently been optimally selected and the effective direction of all control surfaces is correct.

The taxi testing was completed with acceleration tests to check the performance of the engines and with a few "first" hops on the runway to check the aileron and rudder effect and to be able to estimate the speed at which the aircraft would actually fly. Here, a lift-off speed (V_{LOF}) for windless conditions of 16-18 m/s could be determined with the help of the built-in GPS. A V_{-stall} of ~ 14.6 m/s at 0° bank angle was calculated. For the first flight, $V_R = V_{-stall} \times 1.4$ was set.

Another and very important part of the taxi testing was checking the radio link between the ground remote control station and the aircraft. Both, for controlling the aircraft (command link), and for the retransmission and the recording of telemetry data (telemetry link). Evaluation of this data showed no signs of a restricted radio connection on ground and all telemetry data were completely transmitted and recorded. The "Accelerated/Stop Distance", for example, could then be determined from the recorded GPS data. A not entirely unimportant parameter when an aircraft and its landing gear do not have a brake.

This means that many of the necessary technical data for the aircraft have already been determined, all of the aircraft's systems have been checked and all the conditions have been met in order to be able to dare the maiden flight.

As the final point of the taxi testing, acoustic warnings were generated on the basis of the data determined in the remote control station, which should audibly warn the pilot in the event of certain events (e.g. V_R, low speed, etc.). A total number of fifteen low speed and high speed taxi tests were carried out.

4. First flight

Just a few weeks later the first flight took off under ideal weather conditions only the sun was already a little low. Visibility was more than ten kilometers and the wind was calm. The planned course of the first flight basically consisted of two traffic pattern, each with two 180° turns, the flight sections between the turns and the necessary climbs and descents. The most important objectives for the first flight were to carry out a first check of stability and controllability, an assessment of the propulsion system power and a safe landing. The landing gear should remain down for the entire maiden flight.

The aircraft was taxied to the beginning of runway 25 (well before the threshold marker), aligned approximately to the centerline of the runway, and the throttle was pushed to full power.

Fig.3 Ready for departure, Photograph G. Leonhardt

With a current consumption of 98 A for the two impeller engines, the aircraft accelerated rapidly. In the beginning slight corrections of the direction with the nose landing gear steering were necessary, but the aircraft stabilized with increasing speed and was very stable in the directional movement. After seven seconds reaching the V_R, take-off and climb were initiated by slightly pulling the elevator stick.

Fig.4 First flight takeoff, Photograph G. Leonhardt

After the desired climb angle was set, the elevator stick could be released slightly and the aircraft maintained the set climb angle. The climb angle set resulted in an initial rate of climb of 3 m/s. By the time the first 180° turn to the right was initiated, the speed had increased to 26 m/s and no corrections to the horizontal bank angle were necessary. In order not to fly through the sun, the first turn was initiated at a height of about 10 m above the runway, which was about 25° to the right of the runway.

Fig. 5 First turn, Photograph G. Leonhardt

The climb was still stable and the set bank angle had to be supported a little with the aileron. At a height of 30 meters above ground level (AGL), the turn on the opposite course to the runway was ended by a slight counter-aileron deflection and the climb angle was slightly reduced. By the time the second 180° turn was initiated, a height of 42 meters AGL had been reached with an average rate of climb of 2.5 m/s. The second 180° turn was also easy to control and was able to be guided relatively precisely to the runway course. A first approach followed along the runway at an altitude of 65 meters AGL. With the initiation of the third 180° turn, the second, slightly larger, traffic pattern began, still climbing slightly at an altitude of 72 meters AGL. This turn was diverted to a course of 65°, i.e. with a slight offset of 5° to the left of the opposite course to the runway. The throttle control stick was now reduced to approx. 70% and the climb ended by gently pushing the elevator control stick. At least that's what it looked like to me from the ground.

However, the flight data showed that the aircraft was still in a slight climb and had climbed to an altitude of 87 meters AGL before initiating the fourth and final 180° turn. Only after the first third of this turn I did notice my little misjudgment. The throttle stick was reduced to 30% and a steady descent with an average rate of descent of 4 m/s was initiated by pushing the elevator again. Recovering from the turn on the landing track course was successful. Smaller corrections with the roll stick, to land as precisely as possible on the center of the runway were made with the ailerons only. The intercept point from the descent was hit well and the touchdown at the beginning of the runway took place at a horizontal speed of 18 m/s and a vertical speed of almost 0 m/s, but a little too short to the marked touchdown point.

Fig. 6 Flight path of the first flight, Graphic from Google- earth and GPS- Data

5. Conclusion

The taxi tests carried out showed that the aircraft and the ground control station were ready for the maiden flight. They were also sufficient to familiarize the pilot with the handling and operation of the aircraft via the ground control station. From the pilot's point of view, the tests carried out were sufficient to dare the first flight and gave the pilot a good feeling. The first flight could be carried out without any difficulties and was uneventful. The pilot's first impression of stability and controllability of the aircraft was good. And the first flight could be completed with a safe landing.

The first flight could take place according to plan and has shown that nothing stands in the way of further testing. Both the taxi tests and the first flight have provided the necessary technical data of the aircraft and are now the starting point for further testing the small unmanned aircraft system. By the way, this flight was the first flight of a 5th generation combat airframe design that was completely developed and built in Germany.

6. References

[1] RTO AGARDograph 300 Flight Test Technique Series – Volume 27, Unique Aspects of Flight Testing Unmanned Aircraft Systems
[2] JETI DC-14 manual pdf
[3] RTO AGARDograph 300 Flight Test Techniques Series – Volume 14 Chapter 9 – PRE-FLIGHT TESTS point 9.9.2